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Technical Lesson 60

VACUUM TUBES USED IN TRANSMITTING

The fundamental principle of operation of all three-electrode vacuum tubes is alike even though their physical appearances may differ. Thus, the various types of transmitting power tubes and small receiving tubes operate similarly when used for the same purpose; as for example, all tubes function alike when used as amplifiers.

The development of power vacuum tubes has kept pace with the demands for a high percentage of efficiency in the operation of all equipment used in radio communication, both in the field of telegraphy and telephony. All power tubes are rated for their power output. In the following paragraphs we will treat on the various tubes from the smallest one which is accorded a place in the power class, the 7.5 watt type, upward and including the water cooled type rated at 20 kilowatts.

Before dealing with any specific types we will review some important features regarding vacuum tubes in general and especially about power rating. The three circuits associated with the three-electrode tube are designated by the letters A, B and C. These circuits are, respectively, the filament, plate and grid.

During the normal operation of a tube the grid and plate become electrically charged bodies and since they are suspended within the glass envelope in a position surrounding and facing the filament both grid and plate necessarily exert their individual influences upon the electrons given off by the filament. Remember that any electron ejected by the filament is actually in clear free space and being a negative charged particle it is subject to the influence of any body with an electric charge upon it, for such bodies set up electrostatic lines of force between themselves and other bodies. It will be noted that the ends of the grid and plate circuits outside of the tube are always attached to some specified point along the filament circuit. These connections are called the grid and plate return leads and represent the low voltage or low potential side of the vacuum tube circuit. Thus, in tracing out the complete continuity of either the grid or plate circuits, we would find that they embrace part of the filament. Consequently, the current flowing in either the grid or plate must complete its path through the filament and also through the vacuous space within the tube by virtue of the electrons. Considering the filament circuit alone it is easy to see that it is simply a conductive circuit or we may call it a closed metallic circuit through which the heating current flows.

The filament or "A" circuit includes, in general, a rheostat or fixed resistor to regulate the voltage at the filament terminals, and there is also the equipment necessary to provide the electro-motive force. In many cases this

source of e.m.f. consists of a storage battery or if the filament is heated with alternating current, the battery is replaced and the filament is attached to a low voltage coil on a power transformer. Or in certain types of commercial transmitters, slip rings are supplied on the armature of the motor-generator set to collect the requisite alternating e.m.f. The filament, we may then say, is the electron emitting electrode and it is also known as the "cathode".

The plate or "B" circuit includes, in general, a "B" battery, or a d-c generator to supply plate voltage, and in the majority of commercial equipment a plate voltage rheostat is also supplied. In some cases the d-c. output of a rectifier device is used to furnish plate excitation. The plate is the positively charged electrode in the tube and it is therefore called the "anode". We have mentioned heretofore that the plate functions to attract the emitted electrons and so, when the grid is excited with a fluctuating voltage, the electron flow is varied and thus the plate in our tube serves to supply a fluctuating or a pulsating direct current to operate any device inserted in the plate circuit. The device we refer to may take the form of an inductance, or transformer, or resistor. Such a device constitutes the "load" on the vacuum tube. Power is required to operate the load device in the plate circuit and hence the plate circuit is known as the "output" circuit.

Next we have the grid or "C" circuit which is known as the "input" circuit. The grid circuit is so named because the grid receives its excitation voltages from the currents flowing through this circuit which is always connected between grid and filament. The grid circuit consists of either tuning elements, an inductance and condenser for example, or simply the secondary winding of a transformer. In some circuits fixed condensers are inserted in series with the grid and resistors connect the grid to filament. These condensers should have the correct capacity because the input voltages, i.e., excitation voltages must be carried through them without opposition. Bear in mind that the grid is the controlling electrode, because when supplied with electric potentials (called the input voltages) it will act to regulate the quantity of electrons reaching the plate.

The whole action of any vacuum tube is dependent mainly upon the tiny electrons which are liberated or expelled by the hot filament. These electrons are attracted by the positively charged plate and make up and actually constitute the plate current. Thus, when a plate is maintained at a positive potential it will exert a continuous attraction for the electrons emerging from the hot filament.

A certain value of plate current is necessary to insure the normal operation of a tube, and we know that this value is governed primarily by the quantity of electrons pulled to the plate. If we are called upon at any time to summarize briefly the various factors which control the amount of the electron energy reaching the plate we could state these factors as follows:

- (1) The value of the positive d-c. voltage supplied to the plate;
- (2) The operating temperature of the filament;
- (3) The value of grid bias used; and
- (4) The degree of vacuum existing in the chamber within the glass envelope.

All three-electrode tubes function on the principle that when an alternating or fluctuating voltage is impressed upon the grid at certain frequencies and intensities, the amount of electrons passing through the vacuum space from filament to plate will be made to vary, thus the plate direct current fluctuates constantly and regularly between certain maximum and minimum limits. The frequencies and intensities of the voltages impressed upon the grid depend entirely upon the particular characteristics of the current flowing in the grid input circuit.

While we are relating facts which are more or less general in regard to our vacuum tubes, it may prove both interesting and instructive to point out the similar effects set up in a circuit by either a pulsating direct current or an alternating current.

Although a fluctuating or alternating voltage on the grid causes the plate current to vary in strength from its normal value to either greater or lesser values, yet it must be understood that this plate current can flow only in one direction. The conduction of electrons within the tube is in the direction only from filament to plate. Thus the plate current flow is unidirectional and it should be easy to understand, then, that it cannot be called a pure alternating current. However, we do call the instantaneous variations of the plate current the "a-c component". It can be shown that these variations do produce all of the effects of an alternating current; as, for instance, they set up a changing magnetic field surrounding a coil inserted in the plate circuit and produce a reactance voltage across or between the opposite ends of the coil. Moreover, by the use of a coil of suitable inductance and a condenser the changing plate energy is capable of placing an electrostatic charge in the condenser and the latter than can be used to couple the plate circuit with some neighboring circuit. You will recall from your early lessons that reactance voltage is the direct result of a coil's opposition to any change in the strength of the current passing through its turns. The coil opposes either an increase or decrease in current value. This opposition voltage or, as it is called "reactance voltage", is set up by the changing magnetic lines of force cutting back and forth through the same turns of wire which produced these magnetic lines, that is, the magnetic lines react back upon the turns which set up these lines. This effect produced upon a circuit by a coil when it carries a current which is constantly varying in strength is known as "self-induction". The voltage generated is known as the "induced voltage of self-induction".

Now let us consider some facts concerning the metal which is used in the manufacture of the filament wire. A tremendous amount of study and research has been going on steadily in the laboratories of tube manufacturers to find a metal or combination of metals which would give off an abundant supply of electrons for the least expenditure of heating current.

The three materials used to any great extent are tungsten, oxide-coated platinum and X-L, or thoriated tungsten. Tungsten was the metal generally used before Dr. Irving Langmuir discovered that the rare metal, thorium, was especially rich in electronic energy. He showed that a thorium-coated tungsten filament heated to a temperature of 2,300 degrees Centigrade provided an electronic emission more than ten thousand times as great as a pure tungsten filament

heated to the same temperature. Filament wire may be either coated with an oxide, or the wire is more often treated throughout with the rare material, thorium. So, with a comparatively low heating current, the modern power tube filament gives off a vastly greater supply of electrons than was formerly thought possible. While the fact that the X-L filament requires a much lower power to insure a proper operating temperature than would be the case if other materials were used of equal practical value, yet another quality that this special wire possesses is that the total electron emission for a given power consumption is comparatively long. Thus the expectancy of tube life is prolonged many hours. It is agreed that the operating life of a vacuum tube is one of the most important features. Life expectations shows up wide variations with respect to operative conditions and to some extent with individual tubes of similar type. These facts outline in general the essential requirements of the filament wire used in power vacuum tubes.

The manufacturer designs a tube with the correct length and thickness of the filament wire so that when a specified e.m.f. is impressed across the filament terminals the proper current will flow and heat the wire to operating temperature.

The life of a thorium treated filament is naturally limited for the electron energy is obtained at the expense of the thorium. It is to be expected, then, that during operation of a transmitting set the filaments of the various tubes are constantly evaporating, or being used up, as it were. Electron energy driven off the surface of the wire is replaced by the diffusion of thorium down inside the wire. The thorium apparently boils out and while the actual amount of thorium lost at any given moment is very small to be sure, yet the filament will eventually lose its emission. That is to say, the useful life of the tube will end when the supply of thorium inside the filament is exhausted. Of course, the disintegration and evaporation of the thorium will be very rapid if the filament is operated at too high a temperature. Any power tube is likely to be subjected to a short overload, and the X-L filament type has proven capable of withstanding three times its normal voltage without a burn-out.

Gases are given off by the plate when the tube is overloaded and under such conditions the tube will show considerable color. To reduce the possibility of a hot plate giving off gases during its normal life, the X-L filament type tubes are constructed with molybdenum plates which during the manufacturing process are heated to extremely high temperatures by means of a high-frequency furnace. That is, the eddy currents set up due to high-frequency induction tend to heat the metal parts. Other internal parts of the tube are also brought to high temperatures when the plate undergoes this treatment and thus all metallic parts are heated to a higher point than they ever reach during normal operation. Electron emission is usually lowered temporarily in the event of a severe plate overload, but this condition can often be rectified by the reactivation or rejuvenation process which is explained in the next paragraph. Reactivation cannot be resorted to if an air leak occurs in the tube. The leakage of air is through the glass seals or leads in the base of the tube. A purplish or pink glow can be taken as an indication that an air leak exists whereas a distinctly blue glow would best gases had been released from the metal parts within the tube.

While a tube with a low emission is of no practical use it may still have its relatively inert tungsten wire intact and in this case the wire is capable of carrying sufficient current to heat and light to its usual degree of incandescence. It is often possible to restore a tube in this condition to give additional hours of service by a very simple process called "rejuvenation". This process consists of forcing metallic thorium from the inner recesses of the filament wire to its surface by heating the wire to a temperature slightly above normal for about 15 minutes with the plate circuit open. Voltage must not be supplied to the plate during this operation. This reactivation of the filament should be carried on with the voltage about 15% above the normal as specified by the manufacturer, and in many instances we have given the exact limit for many types of power tubes in the discussions which are to follow.

How vacuum tubes used in power circuits are rated. The power rating of vacuum tubes used in transmitting equipment is computed by the output energy of the device rather than by the input energy. A considerable part of the power delivered to the plate of a transmitting tube is wasted in heat. Transmitting tubes are used in the capacity of either an oscillator, amplifier, or modulator. A modulator tube is so named because of the specific duty which it is intended to perform, but nevertheless, it is a tube actually working with an amplifier characteristic. Hence, we can consider that transmitting tubes are divided into two general classes according to their function in a circuit, namely, "oscillator" and "amplifier". It should be noted that any type of tube may be used for either of these functions.

The power required to energize the plate of an amplifier or oscillator tube may be furnished by either a "B" battery, a direct current generator or rectified a-c. depending upon the particular transmitting equipment. You have learned from previous lessons that a vacuum tube associated with a circuit containing a suitable amount of inductance and capacity and designed to provide a feed-back of energy from the plate to grid circuits through either magnetic or capacitive coupling will be capable of generating self-sustained oscillations at a predetermined frequency. The tube used in a feed-back circuit is always known as an oscillator. The oscillations are known as continuous oscillations because they are consistent in frequency and their amplitudes are uniform in strength; such energy may be said to have a smooth-topped alternating current wave-form. It easily can be shown that a line drawn through all of the amplitude peaks would be a straight line.

We explained in the lesson on "Vacuum Tubes" how any voltage variations impressed upon the grid of a tube would be reflected in the plate current. Now, in a properly designed oscillator system when a radio-frequency voltage is applied to the grid the plate current continues to rise and fall in strength and, due to the feed-back action, the amplitudes of these plate changes cause further variations in grid voltage which result in corresponding variations in plate current, and so on. A slight change in plate current, as for example when a vacuum tube circuit is first placed in operation, should prove sufficient to set up the initial voltage impulse on the grid to start oscillations. In other words an oscillating current will be maintained so long as the feed-back power supplies grid voltage variations of sufficient amplitude to vary the plate current within limits which will again provide

stance, keying may be accomplished by changing the grid bias from a high to a low operating bias. This is done to reduce key clicks or thumps to a minimum, for when such sounds are reproduced they greatly interfere with the reception of the message. Our aim is merely to show one type of oscillatory circuit in which the plate circuit is directly coupled to the upper end of the oscillatory inductance L by a fixed condenser marked C-1, where as the grid is coupled directly to the lower end of L by the condenser marked C-2. Although the frequency of the generated oscillations may be varied by adjusting condenser marked C, the frequency is dependent upon the combined values of L and C. Another type of oscillatory circuit and vacuum tube driving an antenna system is shown in Figure 2, this circuit being part of a broadcasting transmitter. These simple circuits are given merely to suggest conventional types to assist in an understanding of the following explanation concerning efficiency and power rating of a power tube.

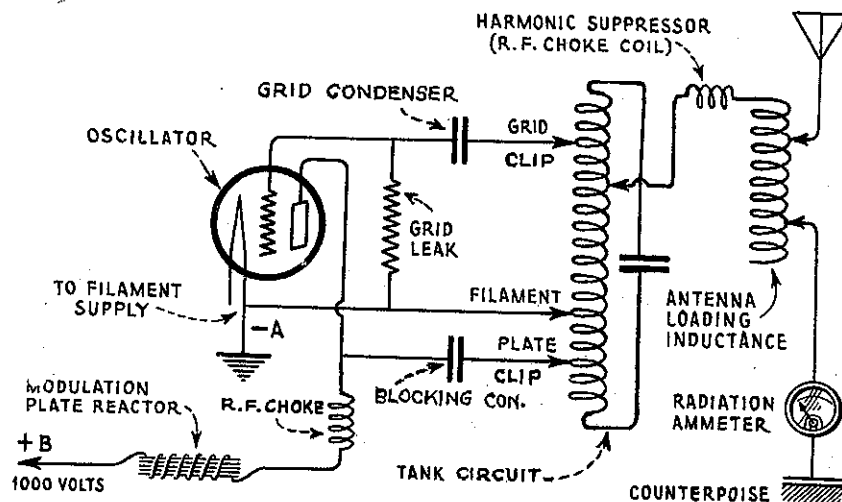


Figure 2

Let us suppose that the power tube in either diagram is rated at 50 watts and, according to the electrical data chart of the manufacturer, the tube draws 125 milliamperes of plate current when the plate is operated with a positive potential of 1000 volts d-c. Then, the power in watts (W) in the plate circuit is equal to the voltage (E) times the current (I), or

$$W = E \times I$$

Note: 125 milliamperes = .125 amperes.

Then $W = 1000 \times .125$ or WATTS INPUT = 125.

It is a simple matter to calculate the watts input. However, to compute the possible power output of this tube working into an antenna system, we will find it necessary in our study to assign two arbitrary values; one for the amount of antenna current (I) which would ordinarily be indicated on the radiation ammeter, and the second for the resistance (R) of the antenna circuit. The output power in watts is conveniently expressed as follows:

$$\text{WATTS OUTPUT} = (\text{ANTENNA CURRENT})^2 \times (\text{RESISTANCE OF ANTENNA})$$

or, using the symbols: $\text{WATTS OUTPUT} = I^2 \times R$

Suppose the resistance of the antenna is known to be 10 ohms from previous experimentation, and the current as read on the radiation ammeter to be 3 amperes while the 50 watt tube is active and delivering power in the form of an r.f. oscillating current for antenna excitation. Then substituting these numerical values for the symbols I and E in the formula, we have:

$$\text{WATTS OUTPUT} = (3)^2 \times 10 = 9 \times 10 \text{ or } \text{WATTS OUTPUT} = 90.$$

Setting down the output and input values in the efficiency formula and solving, we can conclude that the efficiency of this tube is equal to:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \frac{90}{125} \times 100 = .72 \times 100 = 72\%$$

It is obvious that the actual power output of the tube itself cannot equal the power input of the plate circuit for reasons already cited. The power lost is equal to the difference between the watts input and watts output or, in this case, the power lost is equal to 125 minus 90, or 35 watts.

The amount allowed for plate power dissipated in heat, etc., is known as "plate dissipation". This amount should not be exceeded during the normal operation of a tube and a definite limit is set, called the "safe plate dissipation". Since safe plate dissipation is really the power lost it is rated in watts. All power tube characteristic charts list the "safe plate dissipation" in watts for the various types of tubes, and it should now be understood what is meant by this term. A characteristic chart is given at the end of this lesson.

The 50 watt tube in our explanation has a safe plate dissipation of 100 watts. Thus, at 35 watts dissipation, it is being operated within safe limits. Any power tube worked at such a low efficiency as to permit the plate dissipation to exceed the safe limit would be subjected to considerable abuse and in a very short time its ability to supply electronic emission would cease, hence there is only one conclusion or result, the tube's useful life would be shortened.

The interior of the glass envelope of a power tube often takes on a milky white appearance, which condition may be attributed to operating the plate for long periods at an excessively high temperature. This smoky white color indicates that certain gases have been freed from the metal plate. A plate should never be heated to show more than a cherry red.

The heat energy dissipated by the plate of large power tubes, in the one kilowatt class and upward, is normally so high that water cooling is resorted to in order to obtain a satisfactory output of power. Water cooling increases the efficiency of a power tube because it permits the use of a much smaller plate area than would otherwise be possible. A smaller plate reduces the space charge between the electrodes of the tube. The general features of the 20 kilowatt water-cooled tube used in some modern broadcasting equipment is given in a subsequent part of this lesson.

It should be noted that although current is required to heat the filament; i.e. energy in watts is consumed, yet it is not reckoned in the foregoing work on power rating.

Grid current and grid bias. Let us now recount a few facts regarding the grid circuit and the current drawn therein. Only a small grid current should be permitted to flow, and let it be remembered that any current in excess of a certain amount cannot serve any useful purpose. In fact, excessive grid current must be subtracted from the current that would otherwise flow in the plate circuit, inasmuch as the both grid and plate currents originate from electrons ejected by the hot filament. Thus it is possible for the grid to consume energy which is a total waste by the excessive flow of grid current. Under such conditions the grid acts as a load on the vacuum tube resulting in a reduction of its output power. Furthermore, a large grid current will introduce distortion in any vacuum tube. Distortion is particularly noticeable in tubes used in transmitting and receiving circuits which handle speech and musical frequencies, as in broadcasting. A large grid current would most likely heat the grid causing it to emit electrons, and if this condition were allowed to occur the grid would cease to be an efficient controlling factor in providing the proper variations in plate current. Bear in mind that the electrons absorbed by the grid flow as conduction current, i.e., a direct current through the wires, coils, or resistors contained in the outside circuit connected between grid and filament.

From the foregoing it should be clear why a grid must be operated at some definite negative potential maintained upon it at all times. What really happens when a high fixed negative voltage is applied to the grid is that the grid is prevented from actually becoming positive even at such moments as when a positive voltage is applied to it from the currents circulating in the grid circuit. This is readily explained, for the actual voltage upon the grid at any moment is merely the difference between the value of the negative bias and the amplitude values of the fluctuating voltages delivered to the grid from the grid circuit as just mentioned.

Accordingly, the flow of grid current must be controlled and this is easily accomplished by maintaining a permanent negative voltage upon it as already suggested. The value of this negative voltage or grid bias varies for different types of tubes and depends for one thing upon the amount of plate voltage used. The correct grid bias may be supplied by any one of the following methods; (1) the bias may be obtained from a "C" battery inserted in the grid return lead, (2) the grid return wire may be attached to some location on a resistor which supplies the necessary drop in potential when the current flows through the resistor, (3) the voltage drop obtained across a resistor inserted in the negative lead of the high voltage plate supply may be utilized for this purpose, or (4) a small d-c. generator especially built for this purpose is often used to give the requisite bias. The majority of transmitters in radio broadcast work employ either one of the first two methods whereas commercial telegraph transmitters are more likely to employ one of the latter two methods.

With no negative bias on the grid of a power tube the plate current can run up to exceedingly high values, dissipating so much heat that the plate will become white-hot and cause serious damage to the tube.

7.5 Watt Tube Type UX-210. The smallest tube with a power rating is the 7.5 watt tube. It is particularly suited for transmitting circuits where cost and bulk of the apparatus and power supply are prime considerations. This tube is designed for use as an oscillator, modulator or power amplifier in transmitting equipment and it is also intended for use in receiving equipment as a power amplifier with loudspeakers where high output is required. The 7.5 watt tube is used in a large majority of amateur short-wave stations. It is known that under favorable conditions these tubes often supply sufficient antenna excitation to permit messages, carried by the radio waves, to be copied at the opposite ends of the world. These small tubes are also adaptable for use in low powered aeroplane transmitters and for speech amplifiers in broadcasting equipment. When working as a speech amplifier the tube merely functions to step up the necessarily feeble voice and musical frequencies in the output of the microphone to large values before introducing these frequencies into the main modulator-oscillator circuits. The object of amplifying the voice currents is to provide a maximum degree of modulation.

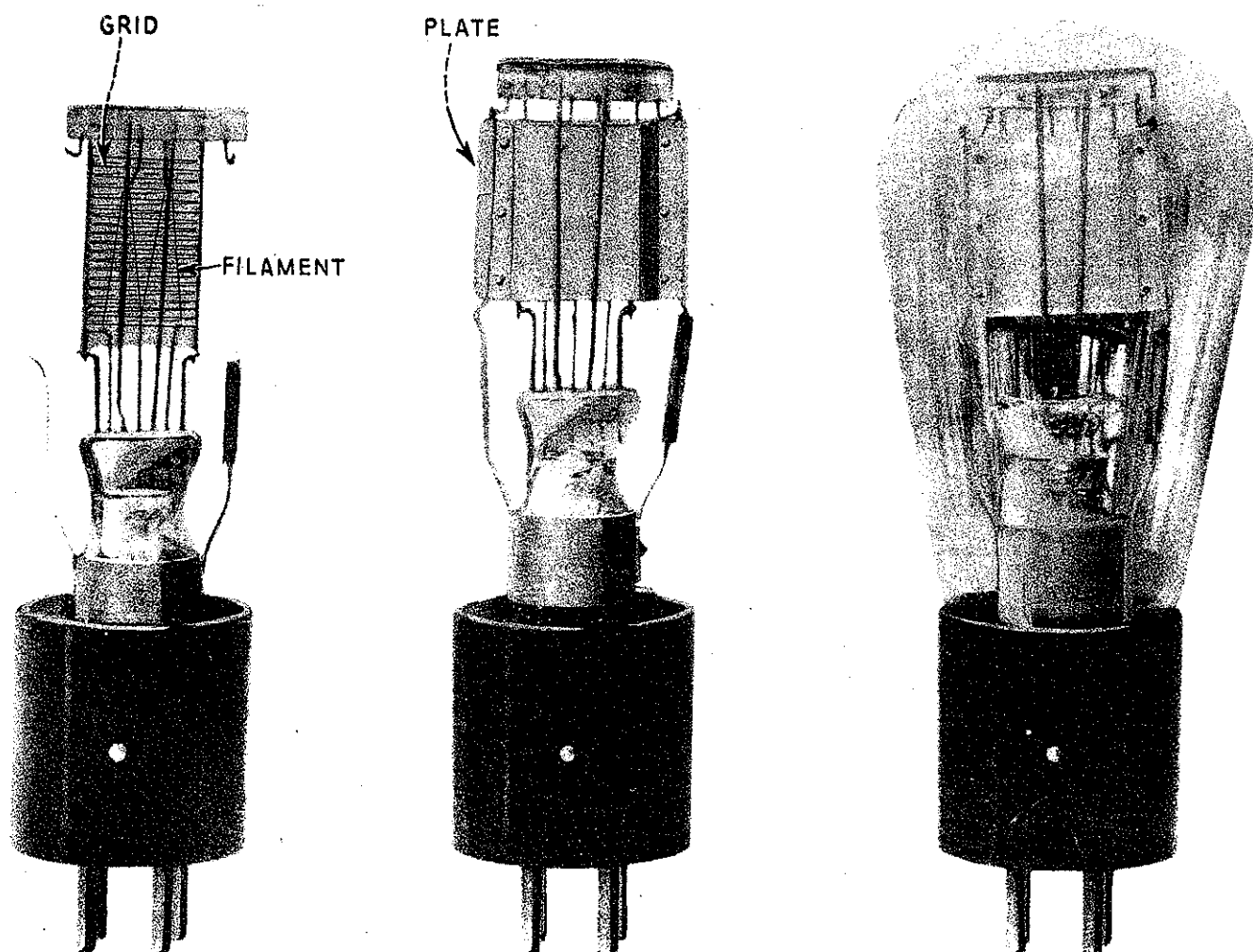
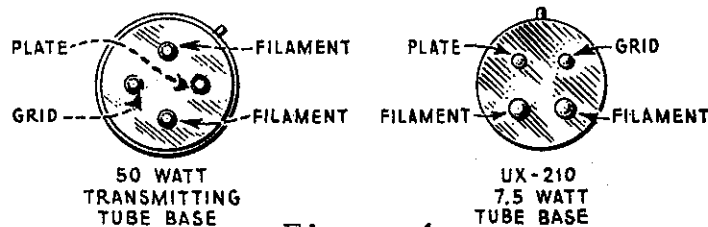


Figure 3

The views in Figure 3 show the complete tube assembly, also the grid, filament and plate construction. A sketch in Figure 4, looking at the bottom of the tube base, shows the location of the prongs. The metal shell of the socket

must not be connected to ground or any other part of the circuit.

The normal output power of the UX-210 is rated at 7.5 watts. The filament draws 2.35 amperes when operated at a filament terminal e.m.f. of 7.5 volts. Care should be exercised to operate filaments at constant voltage rather than constant current and always at the rated voltage. A filament voltmeter connected directly to the socket terminals should be used to indicate correct working conditions. It will be noticed that, due to the use of the X-L filament, its brilliancy is much less than that of the older type tungsten filament. A low emission tube caused by a severe overload and consequent overheating may be restored in some cases by operating the filament at its rated



voltage with the plate voltage removed. This reactivation process can be accelerated by increasing the filament voltage to 9 volts, but not to exceed this value.

When possible, alternating current should be used to heat the filament, but in certain cases direct current is required, as in radio telephone sets and portable sets. The a-c. is in most all cases supplied through a step-down transformer and to provide voltage control a rheostat should be included in the primary circuit of the transformer. With a-c. the plate return lead should be connected to the mid-tap of the transformer secondary, whereas with the use of d-c. this plate lead is attached to the positive filament terminal.

Under normal conditions the plate voltage should never be more than 350 volts, the rated value, and with this plate e.m.f. a plate current of 50 or 60 milliamperes may be expected. The plate power dissipation should never be greater than 15 watts. When this tube is used in a non-modulated C.W. telegraph set (usually called straight C.W.) the plate voltage may be raised to 450 volts in order to obtain extreme output.

The amplification constant of the UX-210 is approximately 7.5 and the mutual conductance value about 2,150 micromhos. These terms will be defined in a subsequent part of this lesson. Let us mention at this time, however, that mutual conductance values are useful for comparison purposes only since the values are computed with the tube operating under zero grid voltage conditions. This does not represent the usual operating condition for we know that in all practical circuits the grid voltage is maintained at some definite negative value and not at zero.

When used as a power amplifier or a modulator the value of the negative bias used should be sufficient to limit the plate dissipation, that is, the difference between output and input, to its normal value or 15 watts. No less than 15 volts negative should be applied to the grid of this tube with a plate.

potential of 350 volts. When calibrating a transmitting circuit it will be noticed that with certain adjustments the plate current is greater than the normal amount although the correct grid bias voltage is used. This effect may be traced to an amplifier tube which is oscillating or perhaps a radio-frequency voltage is being picked up from neighboring circuits. This condition is aggravated by the use of a grid leak having an inductive effect in the circuit. A grid leak should be non-inductive, or in other words, its effect should be that of only pure resistance.

It is advisable to insert either a small choke, or a resistance of 10 to 100 ohms, in the grid circuit of each tube when several are operated in multiple in order to prevent the setting up of ultra high-frequency oscillations.

We mentioned previously that the UX-210 is particularly suited for use in conjunction with loudspeakers in receiving circuits. When employed in this connection the tube is called a "super-power audio amplifier" and is capable of delivering a tremendous output without distortion. The characteristic grid-voltage-plate current curve of this tube is shown in Figure 5. The so-called "straight part" of this curve indicates that the tube is a typical amplifier, for it is easily seen that the slope of the curve follows almost

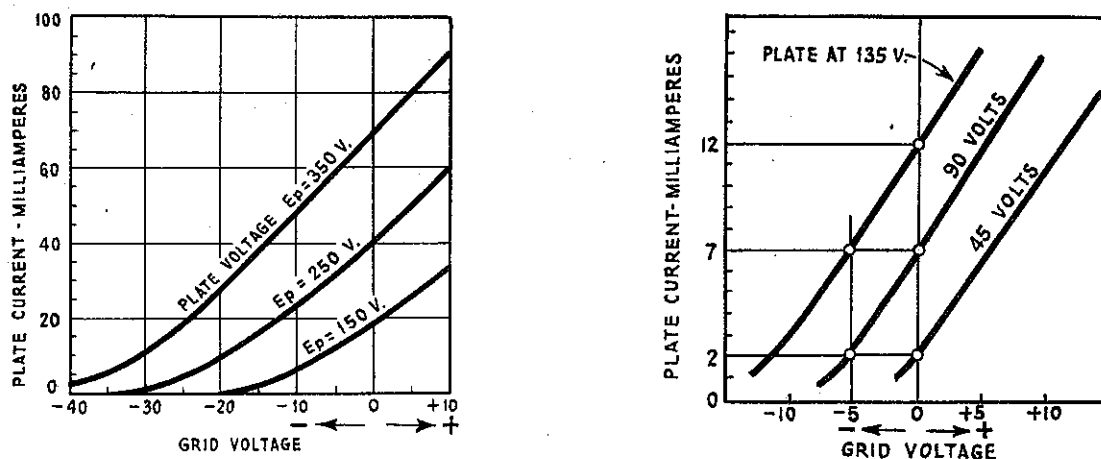


Figure 5

a straight or linear line.

It should be remembered that an efficient amplifier tube provides a greatly enlarged plate current whose pulsations follow in exact accordance and repeat the wave form or modulation frequency of the signal voltages impressed upon the grid. Also, you should fully understand at this part in our course that the only function which the grid is called upon to perform is that of a control member. Any fluctuating voltage, however small, applied to it from any source will cause the electron stream passing from filament to plate, i.e., the plate current, to undergo a corresponding variation. Stated in a few words, this means amplification without distortion. Because of this inherent grid control upon the electron stream we think of the vacuum tube as essentially a voltage operated device.

The straight line variation, as shown by the curves, indicates that the UX-210 can be worked at high or low plate voltages and, with correct grid bias,

will deliver the voice and musical frequencies to the loudspeaker with the naturalness of the original rendition in the broadcasting studio. Undistorted amplification is possible in vacuum tubes possessing such characteristics because large grid voltage swings can be delivered to the grid without it actually becoming positive with respect to the filament. A positive grid would attract excessive electron energy causing a large grid current and as we are already aware this undesirable condition would introduce distortion. The grid return lead of the UX-210 when used as an output audio amplifier should be connected to the negative terminal of the "C" battery. The positive terminal post of the "C" battery should be connected to the negative terminal of the filament.

As mentioned heretofore, low power tubes are used extensively in short-wave transmitters. Conservative plate voltages and power inputs should always be maintained in order to be certain that the tube will not be harmed by excessive voltages, currents, or dissipation within the tube. Abnormal conditions are usually experienced at wavelengths less than 50 meters.

The inter-electrode capacity between grid and plate of the tube provides a path of low reactance for currents of high-frequency, or at the low wavelengths. These currents have damaging effects. At long wavelengths, or high frequencies, the capacity reactances are so high that these currents are negligible. For wavelength adjustments below 10 meters great care should be exercised to prevent brush discharges in any part of the tube which are likely to cause breakdown and puncture of the tube. In order to prevent trouble of this kind it is a good rule to reduce plate voltage as the wavelength is reduced.

50 Watt Tubes Types UV-203A and UV-211. The 50 watt tube is manufactured in two types which differ only in plate impedance and amplification constant. A photograph of a 50 watt tube is shown in Figure 6. Both types are alike in appearance and are operated at similar plate and filament voltages.

The UV-203A is intended for amateur and experimental use where voltage amplification is desired. The UV-211 is used extensively in commercial transmitting circuits for oscillators, amplifiers, or modulators. An inspection of the characteristic chart shows that the filaments of both tubes normally draw 3.25 amperes at 10 volts, the plate power dissipation being 100 watts when operating either tube as an oscillator at its normal plate potential of 1000 volts.

The UV-211 requires a very strong mechanical construction and rigid support of the electrodes since it is used in many marine tube transmitters. These transmitters must stand up under severe operating conditions at sea. The plate is mounted on four separate rods imbedded in the glass stem of the tube. Small helical springs attached to the upper end of the supporting rod

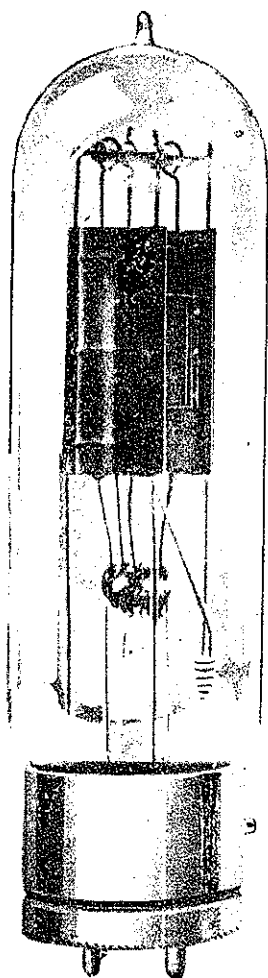


Figure 6

hold the filament wire and maintain it at the proper tension, thus protecting it from shocks. An elaborate spring suspension for the filaments of small power tubes is unnecessary. The sketch in Figure 4 shows the position of the prongs on the 50 watt tube base. Note that the sketch is drawn looking at the bottom of the base.

The UV-203A possesses a very desirable characteristic which protects it from overload. If under any conditions the tube should stop oscillating or lose its negative bias the plate current would not greatly exceed its normal value, as when oscillating. This result is due to the high plate resistance value of the tube. On the contrary, however, in the case of the UV-211 tube, its plate current at zero grid would rise to such excessive values that overheating of the plate would be sure to occur, and in a short time serious damage would result. This inherent plate current characteristic of the UV-211 is due to the low plate resistance of this tube.

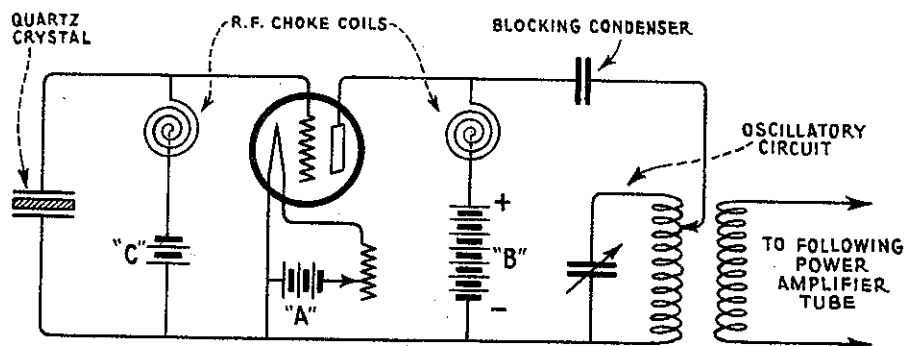


Figure 7

Certain types of modern tube transmitters utilize a crystal controlled master oscillator, several stages of intermediate amplification, and a main power amplifier system. A 50 watt tube is often used with the quartz crystal. The tube supplies power and the crystal dictates the frequency at which the continuous oscillations are generated. Experience has proven that for the reliable operation of crystal controlled oscillators it is essential that low plate voltage be applied to any tube working in conjunction with the crystal. Low voltage permits the transmitter to be operated without fear of subjecting the crystal to excessive voltage which might cause it to crack or shatter. When used in a crystal circuit the 50 watt tube is usually worked at 500 volts d-c. or at half normal voltage. The schematic diagram in Figure 7 shows a 50 watt tube connected in a crystal control circuit. It is preferable to use alternating current to heat the filament and in certain commercial sets this a-c. is supplied by means of slip rings on the motor armature connected to a step-down transformer. A center tap on the transformer secondary should be used for plate and grid return leads. Filament voltage is usually controlled through a rheostat placed in the primary side of the heating transformer. When it is necessary to use direct current to energize the filament then it should be remembered to connect the plate return lead to the positive filament terminal. As in the case of all X-L filaments a voltmeter should be provided to check the e.m.f. applied.

If an overload decreases the electron emission in this tube, the activity of the filament may be restored by the reactivation process which simply requires

that the filament be heated for a period of ten minutes or longer at the rated filament voltage but with no plate voltage. If necessary the filament voltage may be raised to 12 volts but no higher.

A protective fuse which should blow at about .2 to .25 amperes is usually inserted in the plate circuit. Remember that no fuses should ever be placed in a grid circuit since a blown fuse would be equivalent to opening the grid circuit and thus removing the negative bias. A plate voltage rheostat is quite necessary in order that the plate voltage may be lowered in order to protect the tube or other parts in case incorrect adjustments are made, as for instance, when first calibrating a new circuit or making regular adjustments in a circuit. The plate voltage may be increased from 1000 volts normal to 1250 volts only when using these tubes in a transmitter circuit in which the tubes are not actually modulating, i.e., when used in a non-modulated C.W. telegraph transmitter.

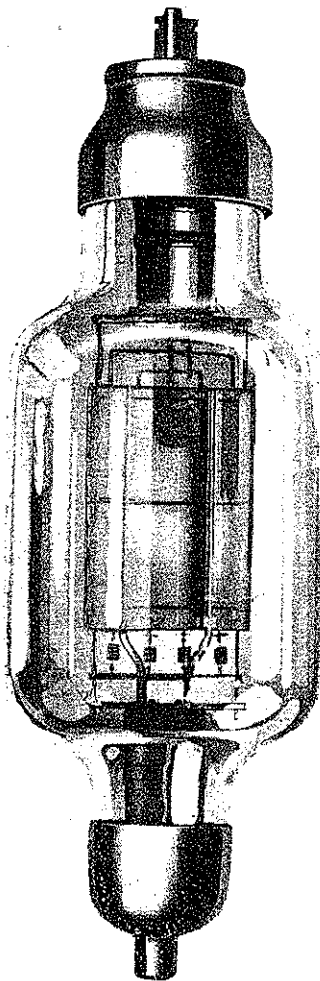


Figure 8

The UV-204A and UV-211 are frequently used at wavelengths of less than 100 meters. Precautions should be taken in every case to keep the currents at safe values, but especially is this true in the case of tubes working in short-wave circuits.

250 Watt Transmitting Tube Type UV-204A. The large UV-204A tube illustrated in Figure 8 has an output rating of 250 watts and it also utilizes an X-L filament. The normal plate voltage is 2000 and the filament is rated at 42.5 watts, drawing 3.85 amperes when supplied with the specified terminal e.m.f. of 11 volts. The maximum safe plate power dissipation is 250 watts. A very high emission is obtained by the use of the thoriated filament, this emission reaches approximately 5 amperes with the filament voltage at 11. The high emission permits the tube to perform very satisfactorily in telephone circuits because the complexities of speech and musical sounds cause large peak values of current

Two or more 250 watt tubes are sometimes arranged in multiple (parallel) to provide a greater output than that afforded by the use of several smaller tubes. The Converted P-8 commercial tube transmitter, found on many ships, employs two tubes of this type arranged "back to back" and obtaining their plate excitation from a-c. at 500 cycles supplied from a 500 cycle a-c. generator feeding into a step-up power transformer. The note received from a transmitter of this kind

whose C.W. is modulated according to the characteristics of a 500 cycle a-c. current is somewhat similar to a 500 cycle spark set using a quenched gap. The theory is briefly as follows: The two tubes are connected with their plates to opposite ends of the transformer secondary. Only the positive halves of the alternating current cycles will be utilized. When one plate is positive the other is negative and it is obvious that only that tube which receives a positive half cycle will be active in generating the continuous high-frequency oscillations. Thus each tube alternately generates C.W. energy

whose modulation is similar to the wave form of the 500 cycle a-c. This is called "full-wave self-rectification".

Since the positive voltages constantly fluctuate between zero and maximum and zero values according to the wave form of the a-c. output of the transformer, then it follows that the resultant modulation produced by rectifying both halves of an alternative current power supply will appear as shown by the curve in Figure 9. There are four completely modulated groups shown in this curve. Each complete modulation produces one click in the receiving head set and since a 500 cycle a.c. is supplied and two tubes are working "back to back," the radiated wave will consist of 1000 completely modulated groups per second, hence 1000 clicks per second will be heard in the head set. This is known as a 500 cycle note and the tone has somewhat the characteristics of a spark transmitter employing a quenched gap as previously mentioned.

1000 Watt Transmitting Tube Type UV-851. The next larger sized transmitting tube has an output rating of 1000 watts. This power is obtainable without any increase in plate voltage over the 250 watt tube. The plate of the UV-851 requires 1000 volts d-c. and its plate power dissipation is 750 watts when the tube is worked as an oscillator.

We have already explained about the high efficiency of a thorium filament

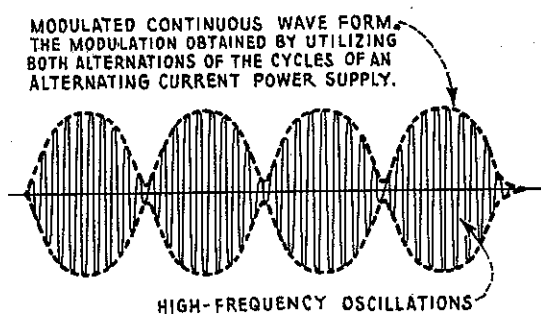


Figure 9

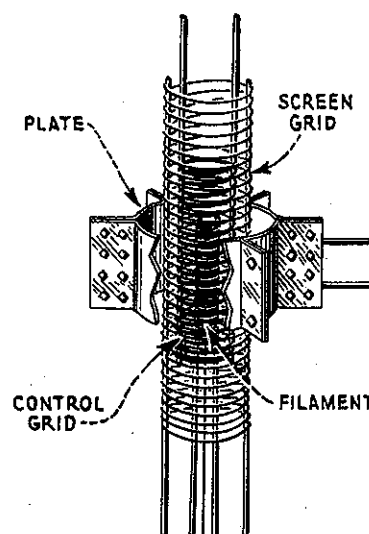


Figure 10

over a pure tungsten filament. This difference in materials, however, may be better appreciated after reviewing the following facts in regard to the practical operation of the UV-851. The X-L filament of this tube requires a power consumption of 170 watts to give a total electron emission of approximately .20 amperes whereas, on the other hand, a pure tungsten filament requires at least 600 watts to give an equal electron emission. In the latter case, i.e., with a tungsten filament, the high emission could be obtained only by considerably overheating the tube; the additional power required would have to be dissipated at the plate. When operated under

certain conditions this tube is capable of delivering a radio-frequency output of 1 kilowatt or more.

The mechanical construction of the 1000 watt type tube differs somewhat from that of the ordinary tube. There are four parallel filament wires used, each wire being supported by a helical spring to maintain proper tension at all times. The grid is constructed of a heavy square mesh of molybdenum wire, it being mounted in a frame which is anchored to the plate structure with an insulator for the purpose of holding the grid in correct mechanical relation to the plate. The heat generated by the plate or anode is dissipated with the aid of narrow wings attached to the plate. These thin metal pieces are called radiating fins.

UX-860 Four-element Tube Output 75 Watts. Extensive experiments with a new four-element tube of the screen grid type have been conducted recently by the engineering staff of the General Electric Company in an experimental 5 meter short-wave transmitter. A special arrangement permits the short-wave set and its antenna wire, which is only 8 feet long, to be suspended at an elevation of 300 feet between high towers. The engineers have been investigating the phenomenon of point to point transmission, meaning in this case that the transmitter and receiver are located many miles apart and no high buildings or hills intervene in a straight line. In other words, the transmitter and receiver are so located that no object of any kind lies in the direct air line path between the two stations.

The UX-860 tube, especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type, is the direct result of these experiments. The high-frequency transmitters send out continuous wave (C.W.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 75 watt tube has a plate, filament and two grids, whereas the standard three-element tube has a plate, filament and only one grid. The addition of the extra grid, called the screen or shield grid, minimizes the effects of inter-electrode capacity, that is, it prevents the so-called feed-back from plate to grid. This stabilizes the circuit in which the tube is used. Whistles, howls and other undesirable effects are eliminated by the addition of the fourth element.

The theory of operation is that the control grid, (the regular grid located adjacent to the filament which is found in all standard tubes), is impressed with the excitation voltages in the manner similar to that for operating any tube, but the screen grid is maintained at a neutral potential with respect to the other electrodes by suitable connection to a source of e.m.f.

The voltage for the screen grid may be obtained either from a potentiometer connected across the plate supply, from the d-c. plate supply through a series resistance of approximately 70,000 ohms, or from a separate d-c. source. The resistance method, using about 70,000 ohms, is the most practical method for maintaining the screen grid voltage at proper value because it provides automatic regulation. When employing the resistance method,

the filament supply should not be discontinued for any reason while the plate voltage is on, for this would cause the full plate voltage to be applied to the screen. When the potentiometer method, or separate source method, is used the screen grid voltage should not be applied when the plate voltage is off. Under operating conditions the screen grid should never be permitted to read a temperature which would cause it to show a color more than that of a cherry red.

When the screen grid is supplied with a suitable positive voltage it acts as an electrostatic screen between the control grid and the plate of the tube.

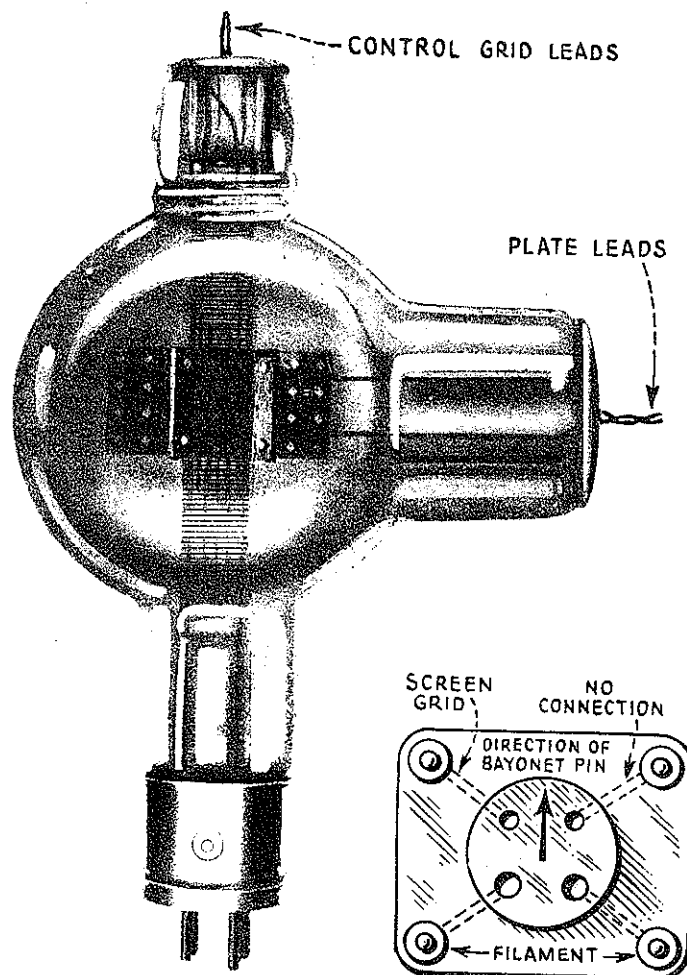


Figure 11

The normal screen grid volts for this tube when operating either as an oscillator or r.f. power amplifier is 500 volts. The need for neutralizing the radio-frequency circuits is eliminated by the use of this tube as we have just stated. The sketch in Figure 10 shows the mechanical relation of the four elements. A photograph of the UX-860 is shown in Figure 11. The UX-860 requires 3.25 amperes at 10 volts for the filament and 2000 volts d-c. for the plate. This tube may be employed as a frequency "doubler" and intermediate power amplifier in short-wave commercial transmitters. When used for this purpose the tube's output is fed into a main power amplifier circuit

which will also use tubes of the four-element type but having a greater output power. A tube especially designed for handling large power at high-frequencies is the UV-861 type.

UV-861 Four-element Tube. Output 750 Watts. Model UV-861 is a four-element tube of the screen grid type, designed for use as a power amplifier in transmitting circuits. It may also be used as an oscillator and is especially adapted for use in short-wave transmitters. One or more tubes of this type are used in the final power amplifier stage and work directly into the antenna. The input voltages for the UV-861's are supplied by one or more UX-860's located in the intermediate stages. The UV-861 is also constructed with a shield grid, and consequently the use of stabilizing methods in the radio-frequency circuits is likewise unnecessary as in the case of the UX-860. The normal screen grid volts for this tube is 750 volts. The inter-electrode capacity is reduced to 0.05 mmfd. by the use of the screen grid. In certain types of transmitters the UV-861 plate is energized by a d-c. double commutator generator having two 1500 volt windings arranged in series to deliver the normal 3000 volts. A plate current of approximately 0.5 amperes will be drawn at this plate voltage. Power tubes are usually provided with a plate voltage rheostat so that during the process of tuning the transmitter the plate voltage may first be reduced and then later increased to normal as the various radio-amplifier stages are adjusted for maximum output in the antenna. The normal d-c. plate current is 172 milliamperes but under certain conditions of service this current reaches values as high as 350 m.a. The X-L tungsten filament takes 10 amperes at a normal terminal e.m.f. of 11 volts.

In a majority of transmitting circuits, power tubes are connected in parallel, which is also known as multiple arrangement. The actual manner in which

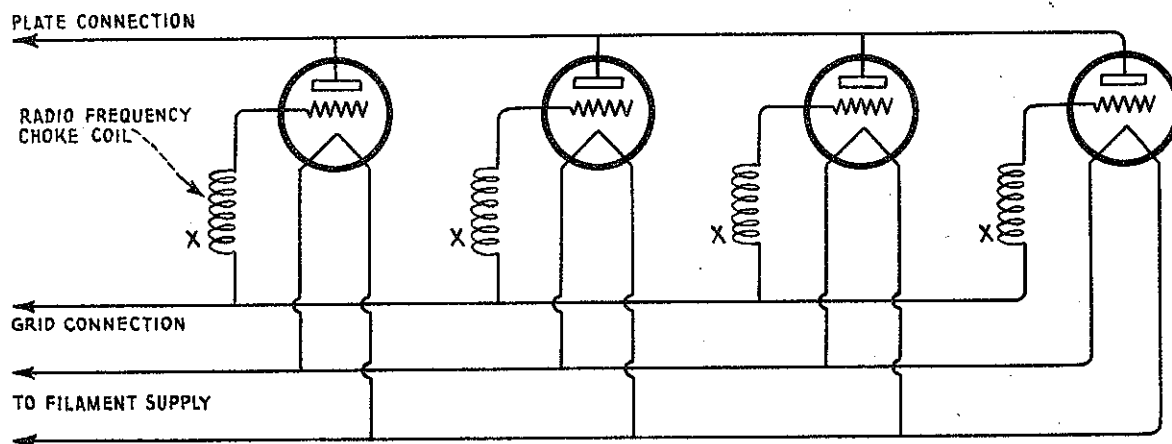


Figure 12

tubes are connected in parallel is in itself a simple method of connecting all the grids together and all the plates together. The filaments are energized from the same source of supply. When power tubes are operated in multiple, a small radio-frequency choke coil or a resistance of suitable size, for instance, one with a resistance of from 10 to 100 ohms should be inserted in the grid circuit of each tube as shown in Figure 12. These coils, or resistors (if used) should be placed as close as possible to the grid terminal of the socket for the purpose of suppressing parasitic oscillations.

The unwanted oscillations are ultra-high frequencies which would circulate through the circuits and cause undesirable effects if no provision were made to suppress them. They are set up under certain resonant conditions existing between the tubes and the coupled circuits.

An amplifier circuit may consist of six or more tubes connected in multiple in order to supply an antenna system with a large power—the sum total of

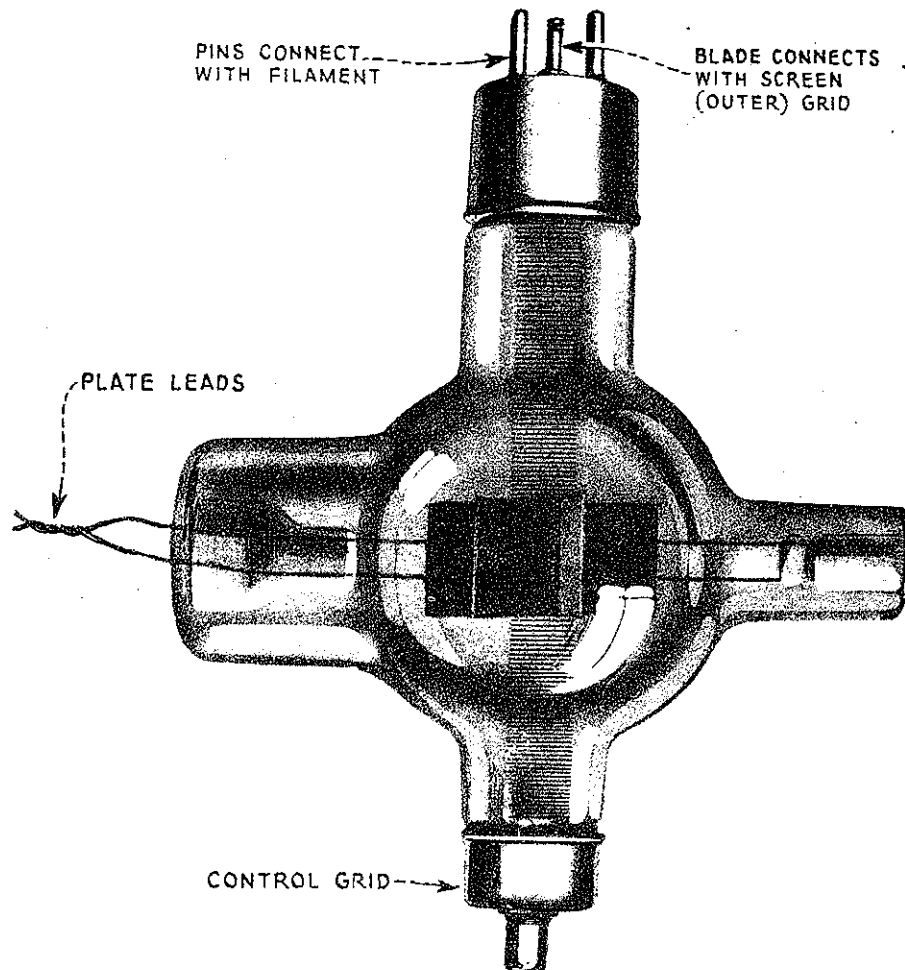


Figure 13

the watt output of the individual tubes used in the system. Multiple arrangement provides a practical means for dividing the load among several low-powered tubes, and in this way the need for a very large expensive tube and power plant is eliminated. A photograph of the UV-861 is shown in Figure 13.

75 Watt Special Short-wave Transmitting Tube Type UX-852. The UX-852 tube illustrated in Figure 14 is designed for use as an oscillator, power-amplifier or modulator in transmitting circuits operating on 5, 20 and 40 meters. It is also well suited for use as a crystal-controlled oscillator by operating it at less than the rated plate voltage. This tube has a very low inter-electrode capacity made possible by its special construction. Its plate to grid capacity is only 3.3 micromicrofarads as compared to 8.0 mfd. for the

UX-210. Observe in the photograph how the plate and grid electrodes are mounted on separate stems with the connecting leads entering the glass envelope through opposite sides. The filament leads are brought to the prongs on the tube base as in the ordinary tube.

On 20 meters, the tube will oscillate with stability and under certain conditions will deliver power on 0.7 of a meter. The UX-852 may be employed as a crystal controlled oscillator with a slight reduction in output or rated plate voltage, made necessary because of the limitations of the crystal.

The double end or T-shaped glass envelope with leads coming out at safe distances from each other prevents damaging base flashes. Connections to each of the grid and plate elements is made through two large stranded leads brought out from each stem as we have just mentioned. These parallel leads permit large circulating currents to be carried safely at the high frequencies and therefore it is imperative that both leads be always used. The X-L filament used in the tube gives a high electron emission. The filament power is rated at 32.5 watts. The tube base should always be mounted so that the filament will occupy a vertical position. Alternating current should be supplied to the filament whenever possible. Plate and grid return leads should be connected to the electrical center (center tap) of the filament heating winding of the power transformer.

Although the normal plate voltage for the tube is 2000 volts, this voltage may be raised to 3000 provided the plate dissipation does not exceed 100 watts. Radiating fins on the plate permit a very large heat dissipation at this point. Because of the impracticability of measuring the output of a tube working on short wavelengths its correct operation may be judged sufficiently accurate by observing the plate. Plate temperature should never be permitted to increase above a certain value that would cause it to become more than cherry red in color. If the plate is heated to a cherry red, this color may be taken as an indication that the energy dissipated in heat is equivalent to 100 watts, resulting from electron bombardment of the anode or plate. Remember that whenever a circuit employing this tube is adjusted, the tube loss, that is, the difference between output and input, must always be kept within the safe limits of 100 watts.

The filament of this tube may be reactivated, like the X-L filaments of tubes previously mentioned, by operating at the normal filament voltage for ten minutes or longer with the plate voltage supply disconnected. The activity of the filament may be accelerated by increasing the filament voltage to 12 volts, but no more. In cases where an overload has liberated a large amount of gas this reactivation process will not be successful.

A fuse of the proper size to blow at 10 amperes should be inserted directly in series with the plate supply lead in order to protect the grid, wiring etc., from overheating when improper adjustments of the circuit have been made. As we have cautioned before a fuse should never be placed in the grid circuit of any tube, because if it should accidentally open or blow it would remove the grid bias from the tube with the result that the plate current would immediately run up to a dangerous value.

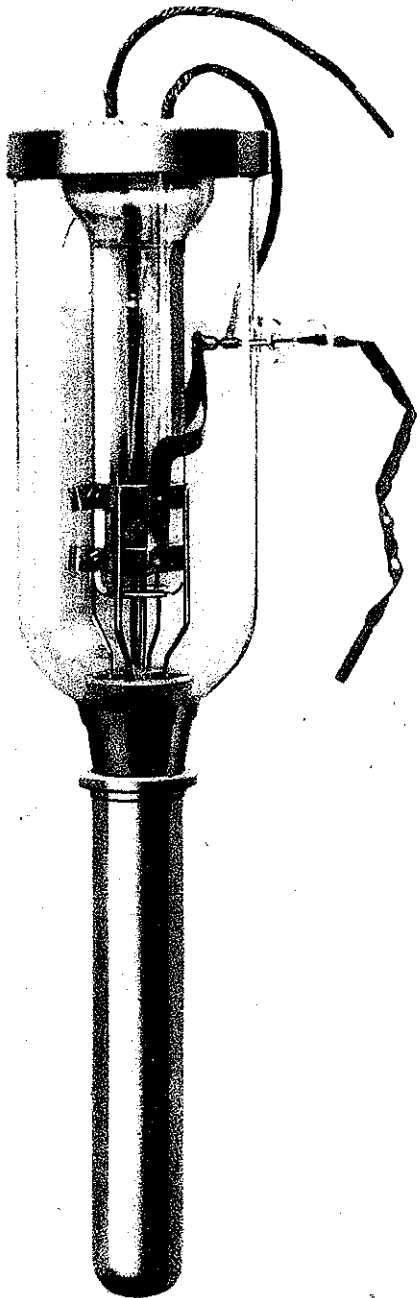


Figure 15

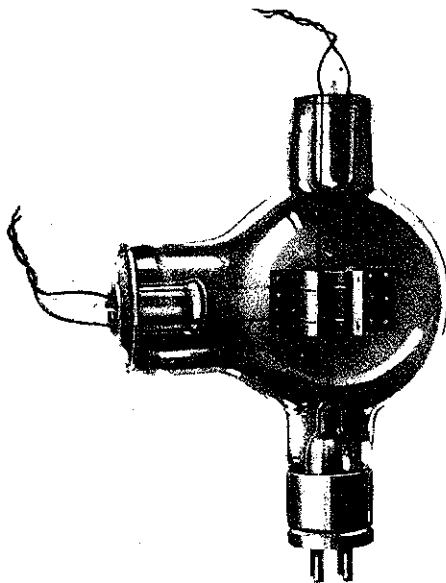


Figure 14

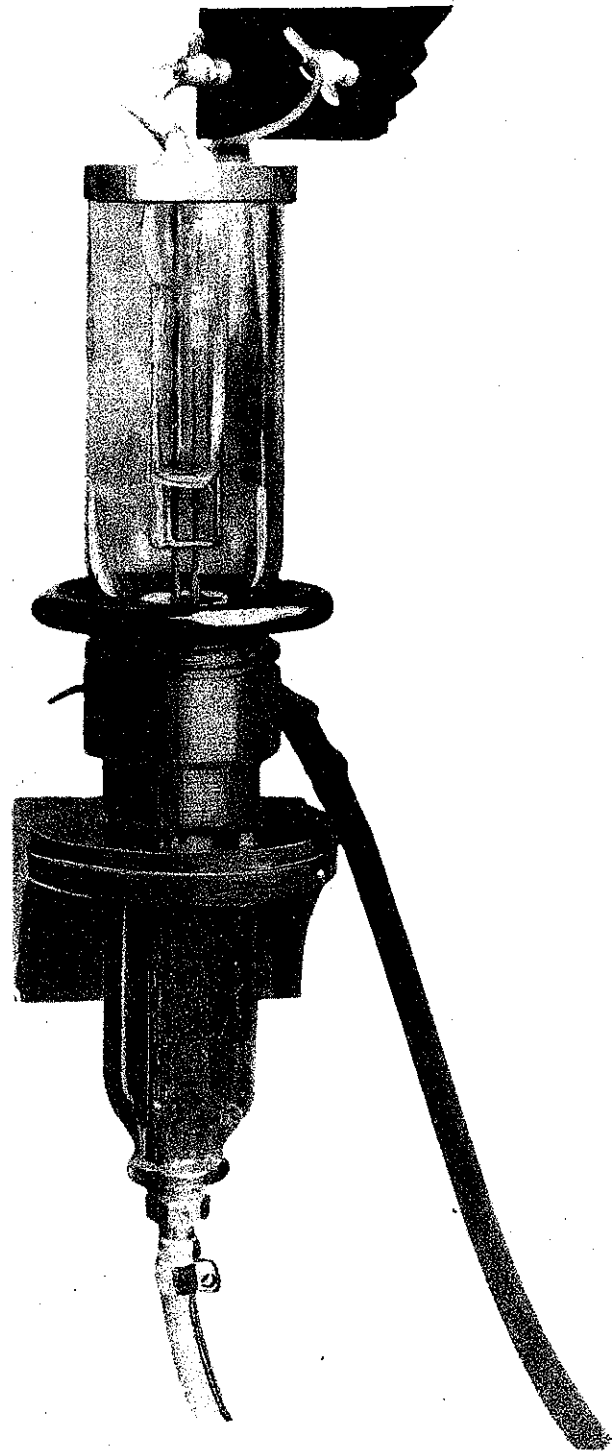


Figure 16

The following suggestions and important "don'ts" are applicable to all tubes in the power class and should be heeded by anyone working with transmitting equipment:

Never permit a plate to heat above a cherry red color under any circumstances.

Never use excessive filament or plate voltage.

Operate the tube at relatively low plate voltages whenever circuit experiments or regular adjustments are made in order to protect the tube and other parts in case the adjustments are incorrect.

Handle a tube with extreme care whenever removing or placing one in its socket.

Do not permit a spray or drops of water to fall on the glass envelope.

Institute regular cleaning schedules, and at intervals of about a month remove the tube and clean the prongs, metal parts of the sockets, springs, etc.

Do not allow these contact points to become corroded for they would then have the effect of considerably increasing the resistance of the circuit at this point.

20 Kilowatt Water-cooled Transmitting Tube UV-207. This tube is adaptable to either broadcast or telegraph transmitting circuits. Although the 20 kw. tube is one of the largest of the family of vacuum tubes, yet it functions exactly similar to its smaller brothers in the lower power classes. The tube is well suited for use as an oscillator, power-amplifier, or modulator. The enormous power which this water-cooled tube is capable of delivering can be appreciated by noting the magnitude of its various operating voltages. For instance, the plate is energized with 15,000 volts and the current drawn in the plate circuit when the tube is oscillating is 2 amperes, or 2000 milliamperes. The radio-frequency current, or oscillations generated by this tube, circulates through the grid circuit and reaches values up to 30 amperes. A grid d-c. current of about 100 milliamperes can be safely carried by the grid. The filament e.m.f. is 22 volts which gives a filament current of nearly 52 amperes. A filament starting resistance is necessary in order to raise the filament temperature gradually, and when the normal operating point is reached the plate voltage is automatically applied.

While the rated output of this tube is 20 kw. the maximum safe plate dissipation is 10 kw. It will be recalled that lost power is generally dissipated in heat. The long copper cylinder shown at the bottom in the photograph of the tube in Figure 15 is the anode or plate. By inserting the anode in a water-cooled jacket the heat produced at the plate is quickly extracted. The complete water-jacket assembly is shown in Figure 16. A good idea of how a tube is mounted in a water-jacket can be had from the interior views of the new operating room of the National Broadcasting Company shown in Figures 18 and 19. A flange screwed to the threaded portion of the plate holds the plate in the jacket and special precautions are taken to insure a water tight joint by the use of a suitable gasket of rubber or other material between the flange and jacket. The tube is supported only by the water jacket.

There is sufficient space between the inside of the jacket and the copper cylinder or plate to permit a column of water to circulate freely around the plate for the extraction of heat generated at this point. About two or three gallons of water per minute is constantly pumped past the surface of the copper anode and through the system from cooling coils. The water circulation is maintained by electrically driven centrifugal pumps. The temperature of the water is usually measured after it has passed the hot anode. This is known as the outlet temperature, 70 degrees Centigrade generally being set as the limit. It is obvious then that the thermometer is located at the point of highest water temperature. The cooling water is never permitted to boil nor are air pockets allowed to form around the anode which might cause overheating of the water. This condition would be evidenced by a singing or buzzing noise from the jacket while the power is on, this noise indicating the presence of steam bubbles at the surface of the anode.

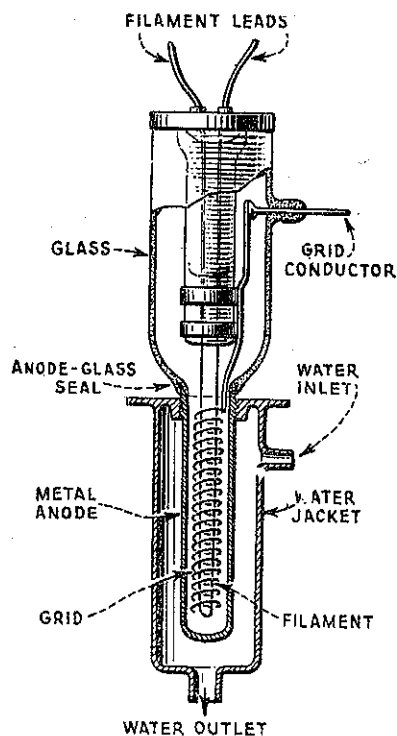


Figure 17

Only water surrounds the metal anode and as can be seen in the photograph the other elements are supported by the glass cylinder with the conductors brought out at safe distances from each other. A simple cross-sectional sketch of the water-cooled vacuum tube is shown in Figure 17. There it can be seen that the plate itself is a hollow cylinder with filament and grid mounted inside. An air-tight seal is made between the copper edge of the cylinder and the glass shell. The tube is very thin and delicate where this union between glass and metal is made.

It may be interesting to note the dimensions of this tube in order that we may compare it with the small receiving tubes which we so frequently handle. However, when we consider the immense amount of d-c. power which is converted into radio-frequency power by this tube, its dimensions do not seem unduly large. The maximum overall length of the tube is 19 5/8" and the diameter of the glass bulb 4 1/4", while the weight of

the tube alone is 2 pounds, 12 ounces. These dimensions seem relatively small and are made possible because of the special means of keeping the temperature within safe limits by both water and air cooling. The air cooling is the natural heat radiation which takes place at the outside glass walls and water-jacket while the water cooling is due to direct conduction from the hot cylindrical plate to the water. It will be remembered that it is the electronic bombardment which causes the plate or anode to become the hottest element in the tube outside of the filament which is a normal condition for the latter.

An interlock or circuit breaker between the water circulating system and the electrical circuits is set to open if the water supply fails for any reason or if the tube develops trouble. The filament and plate voltages are instantly disconnected by the opening of the interlock.



Figure 18

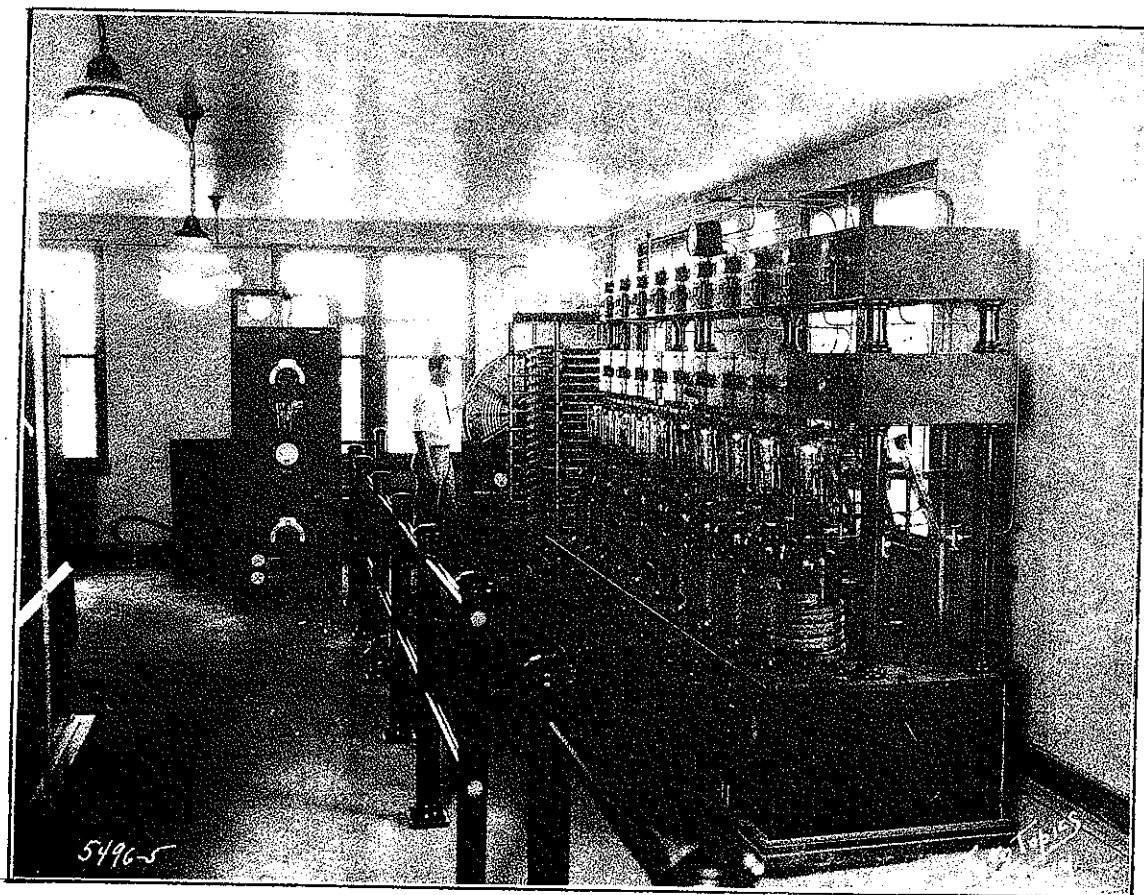


Figure 19

Because of the high plate potential of several thousand volts, the plate must accordingly be insulated from the water tank and metal piping which is normally grounded. The use of a fairly long length of rubber hose connecting the water-jacket to the water source and also, by using pure water in the circulatory system, the insulation and resistance is built up to the order of several hundreds of thousands of ohms. This resistance is between the high potential anode, which is in direct contact with the water, and the cooling system and, in turn, the ground.

A tendency for a heavy scale or deposit to form on the outside of the anode, (the scale being similar to that collecting on the boiler tubes), may be attributed to the use of water containing a high percentage of mineral matter, especially sulphates and carbonates. The chemical content of the cooling water should be determined by analysis. The water must be pure and have a fairly high specific resistance. A length of about 15 feet of $\frac{1}{2}$ " rubber hose is all that is required with high resistance water (4000 ohms per centimeter cube) in order to build up the necessary high resistance between the jacket and the inlet and outlet pipes. Observe in the photographs of N.B.C.'s station how the length of hose is wound around a cylindrical form, a coil being located under each tube in the transmitter.

It can be readily understood that the need of pure water is a very important feature in the operation of large broadcasting stations or any station employing water-cooling for vacuum tubes. The water used in a certain radio station had a specific resistance of only one-tenth that of the water recommended for such purposes. The table below shows the chemical content held in solution in this water, and we give this list for those of our students who may be interested in work of this kind.

	<u>PER 100,000</u>	<u>GRAINS PER GALLON</u>
Silica	1.08	.63
Iron oxide alumina	.25	.15
Calcium carbonate	2.16	1.26
Magnesium carbonate	5.00	2.92
Potassium carbonate	3.86	2.25
Sodium sulphate	3.65	2.14
Sodium chloride	14.00	8.17
Total Solids	30.00	17.52

Specific Resistance 359 ohms.

If the composition of cooling water is such that scale cannot be avoided then it is obvious that the tubes must be removed and cleaned at frequent intervals, the frequency of cleaning depending, of course, upon the rate at which the deposit is formed. The danger of accidental breakage is always entailed in the removal of these tubes because they are apt to stick in the water-jacket. A gentle twisting back and forth and at the same time raising the tube carefully will usually loosen it sufficiently to permit its removal.

In order that the glass envelope will not be subjected to an electrostatic strain the external wiring from the transmitter circuits and the leads attached to the electrodes are kept at reasonably safe distances from the glass.

You will recall that glass is a dielectric material. Hence, electrostatic strains set up by the relatively large oscillating current are likely to puncture the comparatively thin walls of the glass. Again observe the photograph of the 20 kw. tube and note how the two filament leads are brought out at the top whereas the grid conductor comes through the center of the glass bulb. If the filament leads swing and strike the glass at any time trouble would arise from corona, resulting in almost certain puncture of the glass.

A transmitter employing tubes of this power may have the oscillating frequency allocated by the Radio Commission at Washington, maintained within the prescribed limits of 500 cycles by the use of a quartz crystal. A circuit consisting of a quartz crystal, an oscillatory circuit, and a low power amplifier tube, may be set up to supply the initial oscillating current of the desired frequency. This frequency after being stepped-up through several stages of intermediate amplification finally provides a satisfactory amount of radio-frequency voltage for excitation of the grid of the 20 kw. tube.

Immensely large condensers and inductances are required in the radio circuits because of the high potentials present, but actually these bulky units have no greater electrical dimensions than the smaller parts used in low power circuits.

The photograph in Figure 18 shows 32 high power water-cooled tubes in a row. This equipment is part of the National Broadcasting Company's 50 kw. transmitter at Bellmore, Long Island, N.Y. This apparatus has replaced the 5 kw. WEAF transmitter which was located for so many years on Walker Street in New York City.

A general view of the radio-frequency power amplifier and high power tuning system of the station is illustrated in Figure 19. The relative size of the tuning units can be easily appreciated when comparing them with one of the station's engineers standing alongside.

The power modulator tubes are shown in the rear left of the room in Figure 18. The tubes are placed in or out of operation, as the case may be, by relays; each relay being located immediately above the coil of rubber hose. From the engineer's master control desk in the center of the transmitting room one may have a clear view of the 32 high-powered tubes, all of which are equipped with these relays.

MEASURING VACUUM TUBE CHARACTERISTICS

There are several constants by which vacuum tubes of similar type may be compared when operating under exactly similar conditions. We will explain in the following paragraphs how to calculate the amplification constant, plate impedance and the mutual conductance. Although these constants do not enable us to determine exactly how a particular tube will perform in a circuit under certain operating conditions, yet they do provide a very convenient means for us to determine the relative efficiency to be expected from tubes of similar type.

AMPLIFICATION FACTOR OR CONSTANT. μ (μ) is the symbol for this constant.

Amplification constant may be defined as the measure of the effect of the grid voltage on the plate voltage, or stated more fully, it is the ratio of the change in plate voltage to a corresponding change in grid voltage which produces the same effect in the plate current. This relation may be expressed as a formula in the following manner:

$$\text{AMPLIFICATION CONSTANT} = \frac{\text{CHANGE IN PLATE VOLTAGE}}{\text{CHANGE IN GRID VOLTAGE}}$$

With the aid of the curves in Figure 5 we will work out an example that will enable anyone to calculate the amplification factor of any tube whose characteristic curve is available. The three curves show the characteristics of the same tube, a UX-210 tube, when worked at three different plate potentials. The first curve is the 135 volt curve, the second 90 volts, and the third 45 volts.

In our example let us consider only the 135 and 90 volt curves in order to find the ratio of change in plate voltage to a corresponding change in grid voltage which would give a change in plate current exactly similar for each grid and plate variation. Reference to the curves tells us that when working the tube with the grid at zero potential the flow of plate current is 12 m.a. (milliamperes) with the plate at 135 volts. It is readily seen that by reducing the plate voltage from 135 to 90, a difference of 45 volts, we obtained a reduction in plate current of 5 m.a.

Let us now locate a point on the 135 volt curve which tells us the value of plate current for a grid bias of negative 5 volts. To do this we follow the vertical line upward from the -5 location on the bottom horizontal line, (the line upon which the grid voltages are marked) until the vertical line crosses the curve. Beginning at the point of intersection we follow the horizontal line to the left until it meets the vertical line upon which the plate current values are marked. The plate current value is seen to be 7 m.a. However, this same 135 volts, as previously shown with the grid at zero potential, gives a plate current of 12 m.a. Hence, it should be clear that with the tube operating under these two different grid voltages, zero and -5, the plate current dropped from 12 to 7 m.a. Observe now, that we have the same value of change of plate current, or 5 m.a. for two different plate voltages, 135 and 90, corresponding to the two different grid voltages, zero and -5. Briefly, it could be stated that it required only 5 volts change of grid to make the same plate current change that was obtained by a difference of 45 volts on the plate.

Any set of values might be taken from the curve for our example, providing these values are somewhere along the linear or straight portion of the curve. It will be remembered from the lesson on "Vacuum Tubes" that amplification is obtained by working a tube at some location where the slope of the curve is a straight line.

The numerical values in the preceding paragraphs may now be substituted in the formula and then solving we get:

$$\text{AMPLIFICATION FACTOR} = \frac{135-90}{5-0} = \frac{45}{5} = 9$$

Then 9 is the amplification constant of this particular 210 type tube.

Plate Impedance. This constant is the measure of the change in plate voltage to the resultant change in plate current under conditions of a constant grid potential. The term "constant" means that grid voltage remains unchanged or fixed during the procedure of plotting the characteristic curve. Note that grid voltage will not be varied this time, as for instance, in the case of preceding explanation. In this example we can use the same plate voltages and plate current values as in the foregoing examples, when the plate voltage was lowered from 135 to 90 and it was shown that the plate current decreased from 12 to 7 m.a.

After first changing milliamperes to amperes, all of the necessary values can be substituted in the plate impedance formula as follows:

$$\text{PLATE IMPEDANCE} = \frac{135-90}{0.012-0.007} = \frac{45}{0.005} = 9000 \text{ ohms.}$$

Note: 12 m.a. = 0.012 amperes.
7 m.a. = 0.007 amperes.

Then 9000 ohms is the plate impedance for this particular tube.

Mutual Conductance. The mutual conductance value of a tube is a good indication of the efficiency of a tube used as an amplifier, because this value represents the effect of the applied grid voltage upon the plate current. Now then, a certain relationship exists in all tubes between the plate current and grid voltage which the characteristic curve shows in pictorial form. This relationship is when the quotient of the change in plate current divided by the change in grid voltage produces a certain change in question in plate current, providing the plate voltage is maintained constant. Or, it can be said that mutual conductance is the ratio of the amplification factor (μ) to plate impedance. This statement may be written as follows:

$$\text{MUTUAL CONDUCTANCE} = \frac{\text{AMPLIFICATION CONSTANT}}{\text{PLATE IMPEDANCE}}$$

We shall again use the curves of the UX-210 tube to obtain our working values. Observe that with the plate at 90 volts the plate current is 7 m.a. and with the plate at 45 volts the current is only 2 m.a. Thus, a 45 volt reduction on the plate causes a 5 m.a. reduction in current. It can also be seen from the curve that it requires that the grid be changed 5 volts, (that is, from a zero value to -5 volts) in order to effect a similar change of 5 m.a. in plate current. Of course, the plate voltage must in this case remain constant or unchanged when the grid voltage is shifted from zero to -5.

To work out this example we must multiply the 5 m.a. change in plate current by 1000, or 5×1000 , and then divide this result (5000) by the required grid voltage change of 5 volts; we then have $\frac{5000}{5} = 1000$.

	UX-or UV-210	UV- 203-A	UV- 211	UV- 204-A	UV- 851	UX- 852	Screen Grid UX-860	Grid UV-861	UV 207
Rated output (Watts)	7.5	50	50	250	1000	75	75	750	20 kw.
Max. Plate Dissipation. (Watts) or Safe Power Dissipation.	15	100	100	200	750	100	100	400	10 kw.
Filament Volts.	7.5	10	10	11	11	10	10	11	22
Filament Amps.	1.25	3.25	3.25	3.85	15.5	3.25	3.25	10	52
Screen Grid Volts.	—	—	—	—	—	—	500	750	—
Plate Voltage	350	1000	1000	2000	2000	2000	2000	3000	15000
Plate Current Oscillating. (m.a.)	60	125	125	200	875	75	100	350	2 amp.
Amplification Constant. (Approx.)	7.5	25	12	24	20	12	200	300	20
Plate Impedance. (Approx. ohms) at zero grid and rated plate voltage. (See note.)	3500	5000	1900	4700	850	6000	—	—	2000
Mutual Conductance. (Micromhos) at zero grid and rated plate voltage. (See Note.)	2150	5000	6300	5100	23500	2000	—	—	—
Plate Current. (m.a.) at zero grid and rated plate voltage. (See note.)	70	120	320	275	1550	—	85	172	2000
Over-all length.	5 $\frac{1}{4}$ "	7 $\frac{7}{8}$ "	7 $\frac{7}{8}$ "	14 $\frac{1}{4}$ "	17 $\frac{1}{2}$ "	—	8 $\frac{3}{4}$ "	17 $\frac{7}{32}$ "	19 $\frac{5}{8}$ "

Note: These figures are given for comparison only and do not necessarily apply to all conditions of normal operation.

SHORT-WAVE DATA FOR TRANSMITTING VACUUM TUBES
(Safe values for wavelengths above 10 meters.)

Tube	Safe plate voltage D.C. or RMS A.C. (See note below).	Safe Plate Watts.	Safe High Frequency Amperes Through Grid & Plate Leads.	Grid to Plate Capacity. (Mmfd.)
UX 210	350	10	5.	8.0
UV 203-A	1000	75	7.5	22.5
UV 211	1000	75	7.5	18.5
UV 204-A	2000	200	10.	19.0
UV 851	2000	600	10.	57.0
UX 852	2000	100	—	3.3
UX 860	2000	100	10.	.05
UV 861	3000	400	10.	.05

Note: RMS is the abbreviation for Root Mean Square. RMS indicates the actual reading obtained by either an A.C. ammeter or voltmeter connected in a circuit.

Then 1000 micromhos is the mutual conductance for this tube when operating at these particular "B" and "C" voltages, that is to say, at 90 volts plate and zero grid.

The unit "micromhos" expresses the conductance value which is the opposite to resistance. Resistance is measured by the unit "ohm", and notice that "ohm" is spelled backwards or "mho" to express conductance. Furthermore, the prefix "micro" indicates a millionth part of the unit "mho".

Any change in either plate voltage or grid voltage will cause the mutual conductance to vary, and consequently mutual conductance can be expressed only for one set of conditions, i.e., with the tube working at particular "B" and "C" voltages.

EXAMINATION - LESSON 60.

1. Name as many factors as possible which govern the amount of current drawn in the plate circuit of a vacuum tube.
2. What is meant by "safe plate dissipation"?
3. (a) How is a power tube rated? (b) Write the formula for efficiency in terms of watts. (c) Suppose the output of a tube is 69 watts and the input 115 watts. Find the efficiency of this tube in percent.
4. What material is generally used for filament wire in power tubes. Why?
5. (a) State as many reasons as you can that makes the reactivation of a tube necessary. (b) In general, what method of procedure would you conform to in order to reactivate a tube?
6. (a) Why should the amount of grid current in a power tube be controlled? (b) State several ways how this may be accomplished.
7. (a) How are ultra-high frequencies suppressed in coupled circuits consisting of two or more power tubes? (b) Of what practical importance is the four-element tube? (c) What is the fourth element and in a general way what is its effect within the tube?
8. (a) How may several power tubes of similar type be connected in order to supply a large output power to an antenna system? (b) Draw a simple sketch showing three tubes connected in the manner suggested by your answer to question 8(a) immediately above.
9. (a) Should a fuse be placed in series with the grid of a power tube and why? (b) What practical indication have you that a tube has reached its limit of plate temperature and what limit should never be exceeded? (c) What actually causes a plate to become hot and show color?
10. (a) What features make it possible to build and operate a tube of such relatively small dimensions but having the enormous power rating of 20 kilowatts? (b) How is the high voltage plate of a water-cooled tube maintained at a safe operating potential with regard to the water supply tank and other parts which are normally grounded?